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DISPLAYS

Gas desorption electron stimulated during operation of field emitter-phosphor screen pairs

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Abstract

Gas desorption from field emitter array (FEA) cathode and phosphor screen anode in a flat panel display during lifetime operation can affect cathode electron emission and degrade display performance and uniformity. We have measured the outgassing products from selected FEA-phosphor pairs in an ultrahigh vacuum system equipped with a calibrated quadrople residual gas analyzer. Different low voltage phosphors and blank anodes were studied. A Spindt-type FEA was used as the electron source. A unique carousel was used so the desorption from all these different anodes could be measured without intervening vacuum breaks: this allowed the desorption from the different anodes to be directly compared to each other. Quantitative outgassing rates are given and the implications of the results for the pumping of the flat panel and emission from the FEAs are discussed. © 1999 Published by Elsevier Science B.V. All rights reserved.

Keywords: Field emission displays; Field emitter array; Phosphor

1. Introduction

Operation lifetime and reliability of field emission displays (FEDs) may greatly depend on vacuum conditions inside the display envelope. Gas desorption from a field emitter array (FEA) cathode and phosphor screen anode in a flat panel display must be controlled so that outgassing products released during display operation do not change cathode electron emission and degrade display performance and uniformity [1]. In order to help understand such desorption processes and to help define pumping requirements in FEA displays, we have determined the major species outgassing from selected phosphor screen-FEA cathode systems. The screens were made from YAG:Cr and $ZnGa_2O_4$, candidate materials for use as low voltage phosphors. Outgassing products were measured outside the line of sight of both the FEA and phosphor screens. Therefore, if the FEA-screen pairs studied were in a flat panel display, the products detected would be those pumped by appendage getters or pumps mounted on the flat panel.

2. Experimental

In, order to characterize the behaviour of the combined phosphor-FEA source pairs during operation, the non-condensable outgassing products were measured using a quadrupole residual gas analyser (RGA), as described in [2]. Fig. 1 shows a schematic of the ultrahigh vacuum system containing the RGA. The outgassing experiments were run separately from the luminance measurements described earlier in [3], but were performed under similar conditions using the phosphor samples of the same origin. For each run, the phosphor pair was mounted in front of a 10 000 tip FEA [4] using a 10 slot carousel in a 6 in UHV chamber adjacent to the 6 in chamber containing the RGA. The phosphor anode voltage was kept at 500 V, the emission current was maintained at the level of 50 μA. The area of the screens illuminated by the electron beam from the FEA was estimated to be up to $\sim 1/4\ \mathrm{cm}^2$ ($\sim$ 6 mm diameter). A linear micro-manipulator was used to move FEA assembly from the phosphor sample carousel every time the phosphor sample had to be changed by rotating the carousel. The separation distance between phosphor samples and FEA was 5 mm, the distance was maintained by a spring-loaded mechanism pushing the FEA assembly towards the carousel after changing of the phosphor samples. A special precaution had to be taken to separate the RGA chamber from the analytical chamber by installing two semicircular metal shielding screens in the interconnection tube, as shown in Fig. 1. These screens helped to prevent the stray electrons emitted by the hot filament of the RGA head from exciting the positively biased phosphor samples and thereby contributing to outgassing. Ultrahigh vacuum construction was used through the entire vacuum system. Base pressure in the RGA system was $\sim 4 \times 10^{-8}$ Torr after the entire

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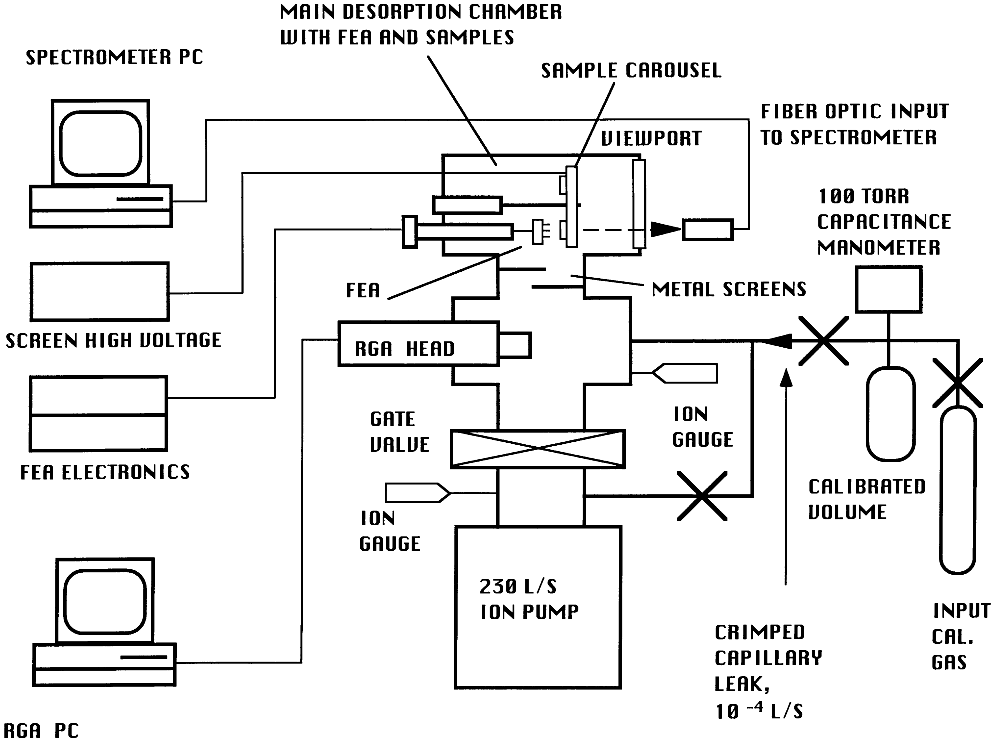


Fig. 1. Schematic of the UHV system for gas desorption analysis.

system was baked to ~ 150°C overnight and allowed to cool to room temperature.

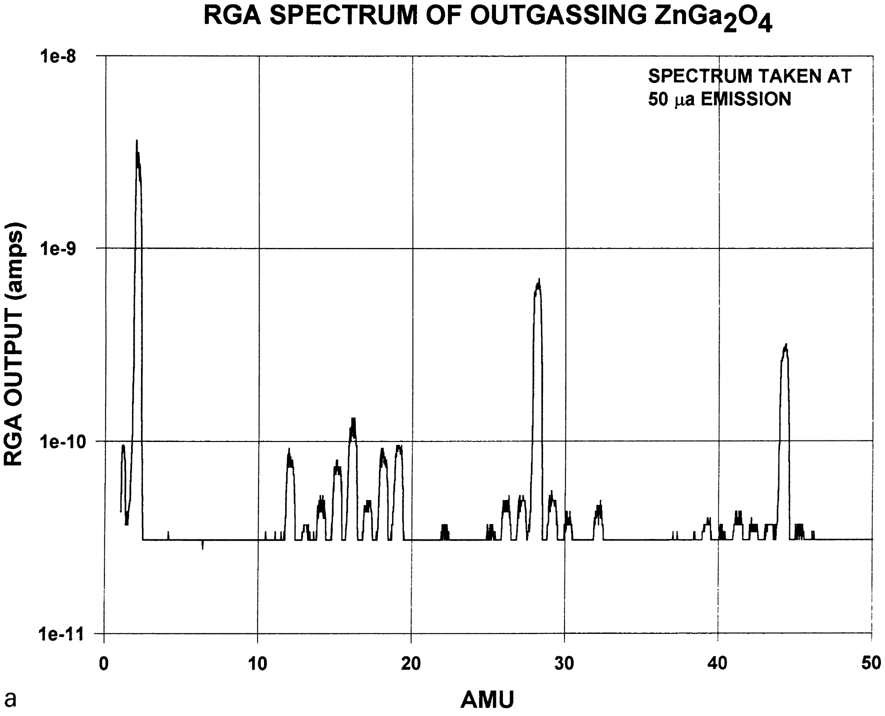
The phosphorus materials were made by combustion synthesis [5–7] and were deposited onto indium tin oxide (ITO)-coated glass substrates by electrophoretic deposition [8,9]. Four separate experimental runs were made, one with a $ZnGa_2O_4$ screen, one with a YAG:Cr screen, one with an ITO-coated glass substrate similar to those used for phosphor deposition, and one with thoroughly outbaked nickel foil screen. A calibration of the RGA response to the gas flows of H_2, CO, CO_2, and CH_4 (methane) was made in the system prior to activation of the field emitter. The desorption experiments were performed primarily to identify the main gas species desorbed from the experimental pairs. During phosphor-FEA operation, both complete RGA spectral scans (1–200 a.m.u., atomic mass units) and selected peak height versus time measurements were taken. Both FEA collector and gate currents were also measured during device operation. In some cases, the luminance of the phosphor was also measured simultaneously with the gas evolution to help completely characterize device performance and to help correlate the current data with those previously acquired with the same phosphor materials [3].

3. Results and discussion

The results of these measurements showed no significant differences in the types of gases evolved from the different screen-FEA pairs. Fig. 2 shows typical RGA spectra for gases desorbing from zinc gallate/FEA (spectrum (a)) and YAG:Cr/FEA (spectrum (b)), both taken at ~ 50 μA screen current. The main peaks in the RGA spectra for both these systems occurred near a.m.u.'s of 2, 44, 28, 15/16, 12, 26–32 and 37–44. These peaks correspond primarily to H_2, CO_2, CO, hydrocarbons (CH_4, C_2H_6, and C_3H_8), respectively, and their fractionation products. No significant peaks above ~ 60 a.m.u. were detected. The ITO/FEA pair also exhibited similar desorption products; however, the desorption rates were lower than observed for the phosphor/FEA pairs. The desorption products detected in the current work are similar to those previously measured in cathode ray tube studies [10,11].

The initial desorption rates measured from 'fresh' phosphor samples are shown in Fig. 3 as a function of incident emission beam current. The data shown was recalculated using the RGA output for the 44 a.m.u. peak, corresponding to CO_2. Other a.m.u. peaks behaved in a similar fashion. The desorption rates from both phosphor samples were quite close to each other and exceeded the rates from an uncoated ITO substrate. The desorption rates from the outbaked nickel sample were significantly (more than an order of magnitude) lower than those of ITO and phosphor screens. We also noticed that the desorption from the phosphor/FEA pairs was prompt, in that the desorption rates for any one sample were directly proportional to the incident current density, and essentially disappeared to background levels when the electron emission was stopped.

The outgassing rates for specific masses of 2, 18, 28 and 44 a.m.u. were monitored during extended operation of the



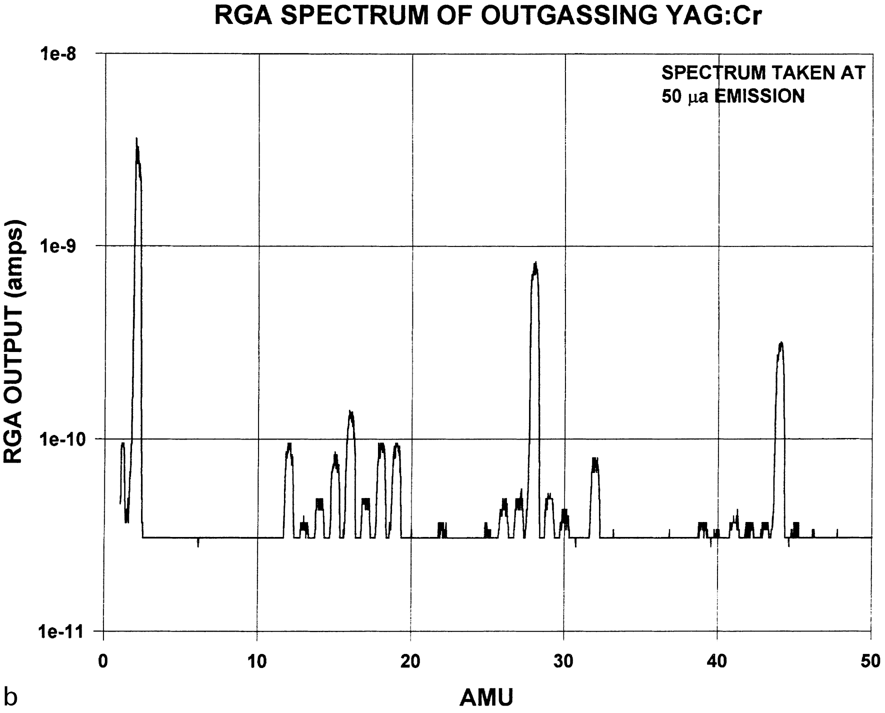


Fig. 2. Typical RGA spectra for gases desorbing from phosphor screens/FEAs at ~ 50 μa screen current: zinc gallate (spectrum (a)) and YAG:Cr (spectrum (b)).

phosphor/FEA pairs for a period up to 16 000 s. A gradual decrease of the outgassing rates from the areas exposed to electron beam were observed for phosphor samples, while the desorption for nickel remained at the same level. Fig. 4 shows the behaviour of outgassing rates for: (a) YAG:Cr phosphor; (b) $ZnGa_2O_4$ phosphor; and (c) nickel samples.

These results indicate that the pair system was being gradually outgassed and demonstrates the importance of considering the past sample processing when comparing desorption data from different screens. Fig. 4 shows that data from different samples should be compared to obtain relative outgassing rates, but only if such samples had the same pre-treatment. It also suggests that effective

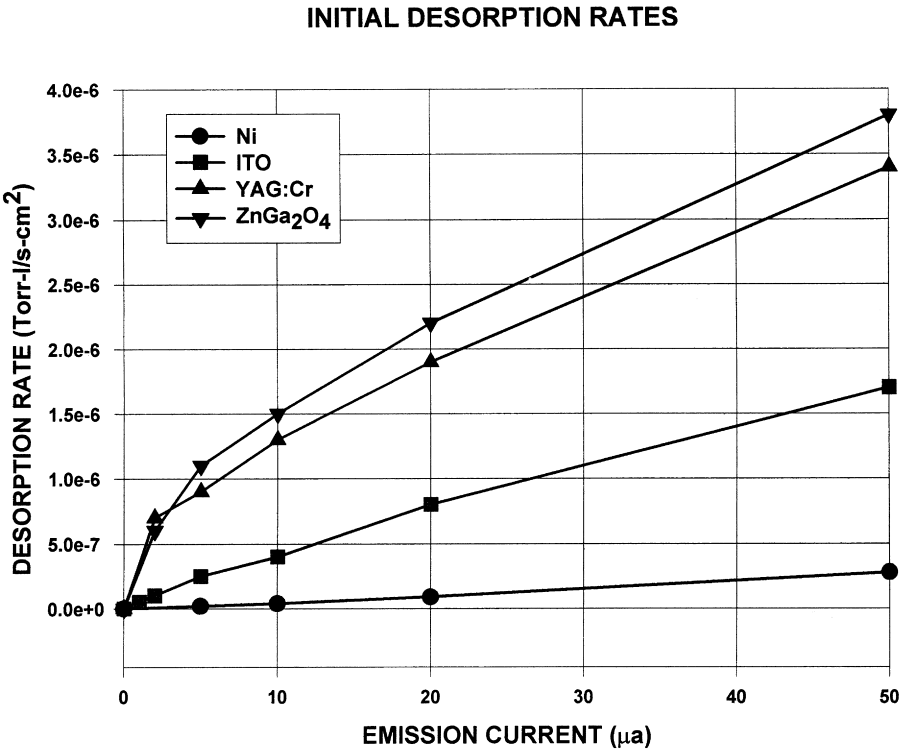


Fig. 3. Initial desorption rates measured from ‘‘fresh’’ screen samples.

outgassing of the pairs could result by running the pairs for extended periods of time.

At some point, the gate voltage in the FEA was reduced to zero, resulting in a corresponding zero screen current. Note the rapid drop in desorption indicated by an arrow in Fig. 4(a). A similar pattern can be seen at the end of the operating cycle (the current of the FEA was cycled on and off a few times at the end of this measurement run). This fact also confirms the electron-stimulated nature of gas desorption from the phosphor versus possible thermal desorption. A thermal relaxation of the phosphor would result in much longer desorption ‘‘tales’’ compared to abrupt behaviour of desorption curves corresponding to the pulsing time intervals of the FEA.

In order to put the current desorption data in perspective, it is instructive to quantitatively estimate the magnitude of the outgassing rates observed in these screen-FEA systems. To do this, the gas inlet system (see Fig. 1) was used to calibrate the RGA response to different gases [2]. Under the current experimental conditions, for example, this response for CO_2 was found to be ≈ 111 Torr-l s^{-1} amp. Thus, the outgassing rate of CO_2 at a screen current of 50 μA would be $\sim 3.2 \times 10^{-8}$ Torr-l s^{-1}, or a specific outgassing rate of $\sim 1.14 \times 10^{-7}$ Torr-l s^{-1} cm^{-2}. This rate far exceeds that of baked stainless steel (10^{-12}–10^{-15} Torr-l s^{-1} cm^{-2} [12,13]) and must be reduced for flat panel applications. Reduction of this rate could be achieved through a combination of increased pre-operation bakeout temperatures and prolonged FEA-phosphor operation prior to flat panel assembly and pinchoff.

Interesting observations were made regarding the sensitivity of the field emission current of the molybdenum Spindt field emitters to background gases. During the calibration of the RGA, different gases were subsequently introduced into the chamber through a calibrated leak at the levels exceeding outgassing rates from the phosphor samples. A direct correlation between the CO_2 level and a depression in the collected FEA current was detected; conversely there seemed to be a weak dependence in an enhancement of current with increased hydrogen partial pressures. These results corroborate observations made for metallic FEA systems [14], and point to the potential loss in screen brightness resulting from a localized gas desorption in a flat-panel display.

4. Summary

Under electron bombardment, all anode-FEA systems desorbed primarily H_2, CO, CO_2, and lower levels of hydrocarbons such as methane, ethane, and propane. The ITO anode desorbed less than the YAG:Cr and $ZnGa_2O_4$ anodes. Direct comparison of the results from anode to anode was not made in the current study because of possible different sample pre-treatments. The results showed that more extensive bakeout and/or pre-treatment by in situ electron

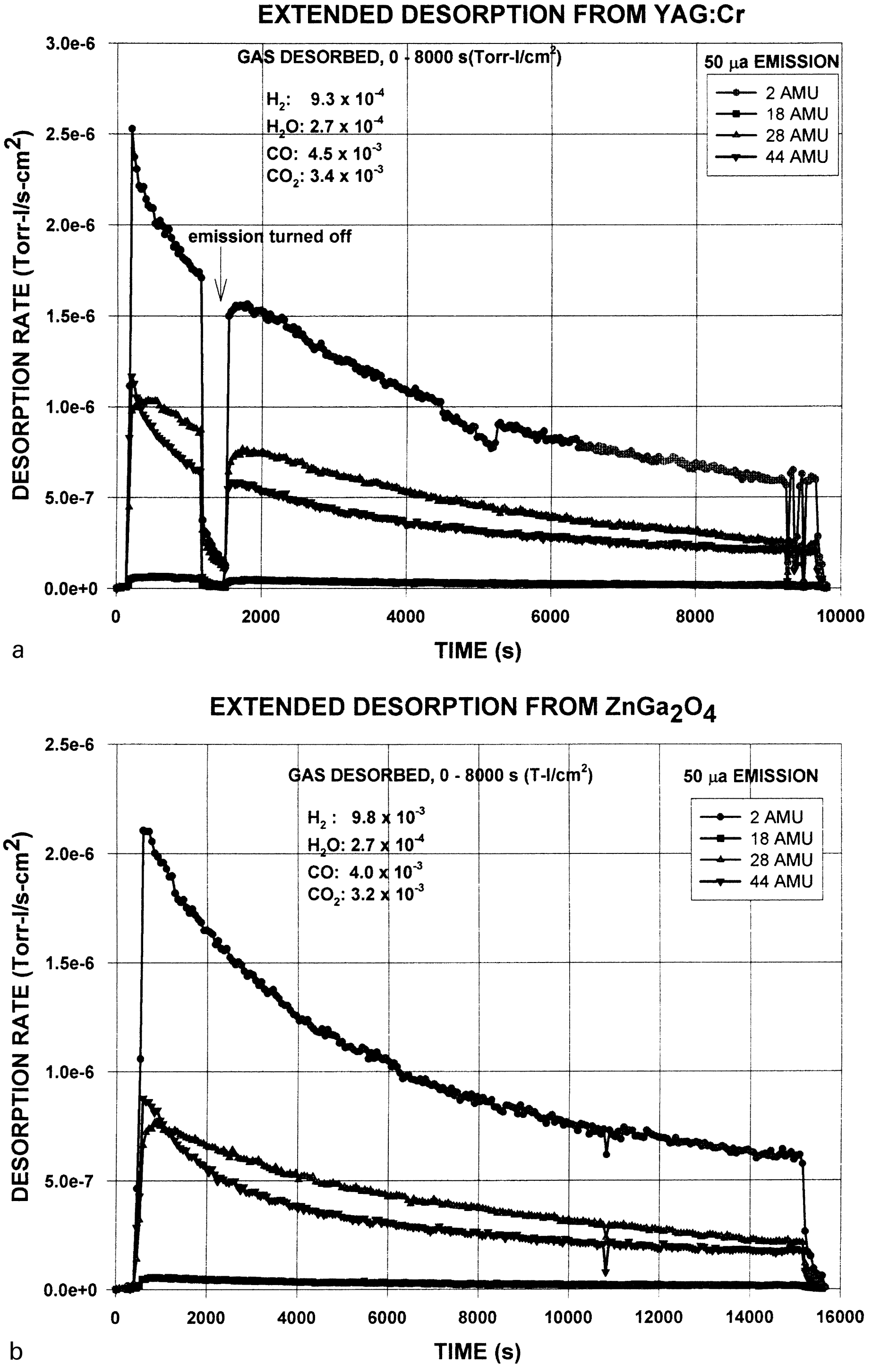


Fig. 4. Extended gas desorption (34 h) from: (a) YAG:Cr phosphor; (b) $ZnGa_2O_4$ phosphor; and (c) nickel foil sample.

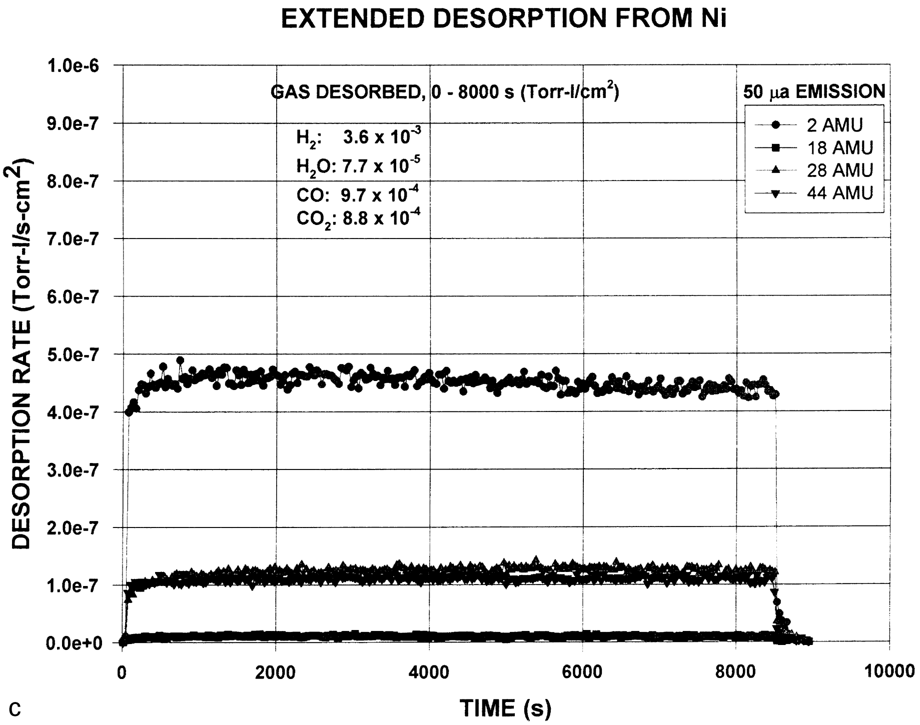


Fig. 4. (*continued*)

bombardment was necessary to reduce phosphor screen outgassing rates to make the screens acceptable for use in flat-panel applications.

Acknowledgements

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